# A conceptual framework for the integrative design of adaptable representation for learning

Stavros Demetriadis, Claude Cadoz

# A conceptual framework for the integrative design of adaptable representations for learning

**S. Demetriadis*,[1], C. Cadoz[2]**

[1] DEPARTMENT of INFORMATICS, Aristotle University of Thessaloniki, PO BOX 888, 54124 Thessaloniki, Greece

[2] INSTITUT NATIONAL POLYTECHNIQUE DE GRENOBLE (INPG) - LABORATOIRE ICA, 46, Av. Félix Viallet – 38000 Grenoble, France

In this work we argue in favor of an integrative design approach supporting the idea that teachers and learners in a technology enhanced learning environment should be able to adapt the affordances of the representations in order to achieve an optimum coupling of the interface to the socio-cognitive learning needs in the specific context. An adaptable interface can appear as a reactive, coactive, proactive or enactive interface depending on the specific learning demands. Such an interface can also functions as a metacognitive tool, enhancing users' understanding of the different modes of the instructional process depending on the varied socio-cognitive contextual factors. We present our very first theoretical considerations pertaining to such an integrative design framework and show how they can be applied in the algorithm visualization domain.

**Keywords** Adaptable learning interfaces; reactive; proactive; enactive interfaces

## 1. Introduction

The affordances of the representations in a learning environment (that is, the user-actions that representations afford for supporting the learning process) are directly related to the learning theories which guide the instructional design (cf. [1]). This results to differentiated designs of software tools which by reflecting different theoretical approaches (e.g. objectivist as opposed to constructivist) offer to learners accordingly oriented learning experiences. The problem that we see here is that users are usually deprived of the option of flexibly adapting the affordances of the representations to the socio-cognitive specificities of their learning situation. This invokes the false idea that working with a specific learning environment may be beneficial for all learners in all situations, understating the fact that learners may experience various levels of cognitive load depending on their familiarization with the representations in use (and therefore should be adaptively supported). It is also a potential hindrance for the integration of software tools in the learning process, in case learners believe that the available tool does not fit well to their learning needs. In this work we argue in favour of an integrative design approach that would allow users to adapt the affordances of the representations, thus achieving an optimum coupling between the learner's cognitive processes evoked by the interface and the socio-cognitive learning needs in the specific context of instruction. In practice, such an adaptable interface would exhibit the functionality of a reactive, coactive, proactive or enactive interface depending on the learning demands of the situation. Moreover, and because of its adaptivity, it can also become a metacognitive tool, enhancing learners' understanding of their own learning efficiency depending on the affordances of available representations.

Applying this theoretical framework in the domain of algorithm animation, we map the level of learner engagement ([2]) onto the features of the interface. This mapping can offer the basis for designing adaptable representations that would flexibly support all these levels of engagement. Such a design, we believe, is of significant practical importance as it is expected to lead to improved learning outcomes and further advance the integration of software learning tools in the various instructional settings.

* Corresponding author: e-mail: sdemetri@csd.auth.gr

## 2. Theoretical considerations

The advent of digital technology made the concept of "interface" become a central notion in learning from and with technology. In a learning situation an instructional interface is a tool mediating the relation between social partners (e.g. teacher and learner) in relation to learning. Therefore, the need for different mode of instruction in different learning situations should be mirrored in the different affordances[1] of the representations in the interfaces of TEL environments.

Varying the affordances of the interface representations, varies the quality of interactivity supported for learners. In the literature ([3]) one can identify at least 3 levels of interactivity, ranging from reactive (where there is little learner control of content structure with program directed options and feedback), to coactive (providing learner control for sequence, pace and style) to proactive (where the learner controls both structure and content). The affordances of the representations in learning interfaces are different in these three types of interactivity.

A reactive interface promotes a specific model of knowledge which should be encoded by the learners. The representations therefore do not afford allowing the learner to explore other possible models. However in constructivist designs the representations afford proactive quality enabling user-learners to transfer to the system and test their hypotheses about the models of knowledge (for example in simulation or microworld environment). The space between reactive and proactive interface designs can be conceptualized as a continuum. In this continuum various degrees of "coactive" designs could be implemented to allow learners to do adjustments in order to achieve perceptually and/or conceptually optimal conditions for understanding the presented material. Moreover, the continuum could be extended to also include the enactive interface. Such an interface is based on the idea of learning by doing (not "doing" in the sense of manipulating representations as in a proactive interface, but in the sense of experiencing a "given environment" through sensori-motor interactions). According to the "enactive cognitive sciences" (e.g. [4]) action and perception are considered as indissociable: we always act to perceive, we always perceive when acting. So, an enactive interface can increase active engagement of the students by developing conditions allowing a "sensory-motor interaction with the representations". This can be achieved thanks to a specific conception of the representation giving to its elements (data, operations, etc.) a kind of physical object status (through physical modeling simulation processes), and an addition of suitable sensory-motor transducers that allow physical interactive manipulations of these "objects" (force feedback gestural transducers). Thus the learner can be "connected" to the representations, ("being himself the representations"), manipulating them in the same way we can manipulate physical objects of the everyday life. Physical modelling simulations and force-feedback gestural transducers are well developed in the domains of Virtual Reality, Sound and Animated Image synthesis and Computer arts ([5]).

## 2. Adaptable interface design in algorithm visualization

In this section we provide a concrete example of how the above ideas could be applied in the case of designing adaptable interface for instruction in the algorithm visualization domain.

The term "algorithm visualization" (AV) (and also "algorithm animation") is commonly used, referring specifically to the use of dynamic visual representations for the visualization of the high-level abstractions which describe software, i.e. algorithms. Animating an algorithm is expected to promote students' better understanding of the structure, intricacies, shortcomings and advantages of the algorithm, even allowing for further optimization.

Studying the literature on the instructional efficiency of the algorithm visualization tools one can reach a certain conclusion: AV systems can be of significant learning usefulness when they are used to

[1] The term "affordance" is used here to mean the allowable actions specified by the design of the interface in response to the learning needs of the learner-user. The affordances therefore set the extent of what the learner is allowed to experience when interacting with the representations in a learning environment.

engage students in active learning situations and not just put them in a passive viewer's position where they simply observe experts' visualizations (e.g. [6, 2, 7]). So, the idea that animated graphics per se would lead to better learning outcomes (without considering any other factors such as advanced interactivity, collaboration and social context) has proved to be too naive. However, other studies support the view that learning is significantly enhanced when visual and linguistic (verbal) elements of information are successfully dual coded in learner's brain. There are several studies reported (e.g. [8]) where the appropriately organized presentation of verbal and visual material resulted in significant better learning outcomes as compared to learning based only on textual learning material. Why does the simple presentation of visuals affect in so different way the learning situation? Still other studies indicate that instructional design effective for novices may even hinder learning of more advanced learners (for example see [8]). Why does the same instructional design lead to different learning outcomes?

To answer these questions we introduce the concept of representational density. A representation is dense for a learner if, for some reason, the learner experiences a high cognitive load when trying to process the information conveyed by the representation. These reasons may include:

- Syntax (the syntactic structure of the representation is unknown to the learner)
- Abstraction (learner lacks prior knowledge on which to "anchor" the abstract representation).
- Complexity (too many interrelated pieces of information are presented overloading learner's working memory).
- Translation (information of the domain is shared between multiple representations and translating between them is demanding, thus overloading also learner's working memory)

The concept of the representational density offers a link between the external representations and how the learner processes them. Various learners experience varied levels of representational density. A reactive interface may efficiently support learners to dual code information when the representational density they experience is relatively low but if the representational density increases (e.g. novices who face new and complex external representations) then the interface has to become coactive, which means that the representations should afford additional opportunities to the learners in order for them to achieve the desired level of comprehension (e.g. adjusting the speed of an animated demonstration or processing information by answering appropriate questions). When the role of the learners changes (a socio-cognitive change) and constructing their own representations is part of the learning situation then the experiences have to become of proactive quality. A proactive interface offers to the learners the opportunity of constructing the external representations (at various levels of density) thus progressively develop not only their internal knowledge representations but also their knowledge construction skills. Finally there are cases when the assumption collapses that knowledge is transferred or constructed by the manipulation of symbolic structures (you can not possibly learn how to ride by studying the concept of equilibrium). The interface has to become enactive and this basically means that appropriate sensory-motor loops have to establish a functional oneness between the learner and the environment in order for the learner to develop the kind of expertise necessary for the task.

In Table 1 we use the "engagement taxonomy" (presented in [2]) to connect between various levels of learners' engagement and the affordances that the interface should adaptively offer.

**Table 1** Connection between the engagement taxonomy and our theoretical framework for adaptability of the interface.

| | Level of Engagement | Explanations | Interface | Affordances of the interface |
|---|---|---|---|---|
| 1 | Viewing | "Viewing" can be considered as the core form of engagement, since all other forms of engagement with AV technology fundamentally entail some kind of viewing. | Reactive / Perceptually coactive | A programmed presentation of information.<br>The learner can react to the prompts of the interface e.g. navigate |

| | | | | |
|---|---|---|---|---|
| | | | | or answer questions for processing basic information.<br>When the learner can also adjust some aspects of presentation to achieve best conditions for the perception of information (e.g. adjusting the speed of the animation) then the interface can be characterized as perceptually coactive |
| 2 | Responding | The key activity in this category is answering questions concerning the visualization presented by the system.<br>For example, learners might be asked questions such as:<br>"What will the next frame in this visualization look like?" (prediction), "What source code does this visualization represent?" | Conceptually Coactive | The interface primes learning by presenting appropriate cognitive activities. |
| 3 | Changing | "Changing," entails modifying the visualization.<br>The most common example of such modification is allowing the learner to change the input of the algorithm under study in order to explore the algorithm's behaviour in different cases | Exploratory Proactive | Representations allow the user to alter basic visualization features at the conceptual level and explore the effects. This explorative feature of the interface is characteristic of the proactive level design |
| 4 | Constructing | Learners construct their own visualizations of the algorithms under study.<br>This can be done in two main ways: direct generation and hand construction.<br><br>Usually construction of visualization is followed by presenting the visualization to an audience for feedback and discussion. | Constructively Proactive | Following a more constructive approach of instruction, the interface enables learners to construct their own visualizations by directly manipulating the necessary material (e.g. enabling the manipulation of the representational code) |

| | | | | |
|---|---|---|---|---|
| 5 | Experiencing | Learners "experience" the algorithm through sensory-motor loops | Enactive | The interface should establish the appropriate sensory-motor loops.<br>An interesting question is: in what cases would an enactive interface support efficiently the instruction in such a highly abstracted domain as algorithms? |

## 4. Conclusions

In this work we argued in favour of an integrative design approach that would allow users to adapt the affordances of the representations, thus achieving an optimum coupling between the learner's cognitive processes evoked by the interface and the socio-cognitive learning needs in the specific context of instruction. In practice, such an adaptive interface would exhibit the functionality of a reactive, coactive, proactive or enactive interface depending on the learning demands of the situation. In the future we plan to (a) develop an ontology for interface affordances, appropriate for becoming the basis of the integrative design framework and (b) explore the socio-cognitive consequences of such integrative design which essentially means to explore the learning efficiency of the proposed adaptable interface design in various learning contexts.

**Acknowledgements** This research is funded as part of the European Network of Excellence "Kaleidoscope" (contract number 507838). http:// www.noe-kaleidoscope.org/. It is also related to the European Network of Excellence "Enactive Interfaces" (IST-2002-002114).

## References

[1] J.M. Caroll and W.A. Kellogg. Artifact as Theory-Nexus: Hermeneutics meets theory-based design. In: Proceedings of the SIGCHI conference on Human factors in computing systems, ACM, 7-14 (1989).

[2] L.T. Naps., S. Rodger, J.A. Velasquez-Iturbide, G. Roessling, V. Almstrum, W. Dann, R. Fleisher, C. Hundhausen, A. Korhonen, L. Malmi and M. McNally. Exploring the role of visualization and engagement in computer science education. Proceedings of Annual Joint Conference Integrating Technology into Computer Science Education. Working group reports from ITiCSE on Innovation and technology in computer science education. Aarhus, Denmark, 131 – 152 (2003).

[3] D.M. Rhodes and J.W. Azbell. Designing interactive video instruction professionally. Training and Development Journal, **39(12)**, 31-33 (1985),

[4] F. Varela, E. Thompson and E. Rosch. The Embodied Mind. Cambridge, MA: MIT Press (1991).

[5] C. Cadoz, A. Luciani and JL. Florens. "Responsive Input Devices and Sound Synthesis by Simulation of Instrumental Mechanisms : The Cordis System", In Music Machine Curtis Roads Ed. MIT Press, Cambridge Mass. (1989).

[6] C. D. Hundhausen, S. A. Douglas and J. T. Stasko. A Meta-Study of Algorithm Visualization Effectiveness. Journal of Visual Languages and Computing, **13(3)**, 259-290 (2002)

[7] J. Stasko and A. Lawrence. Empirically assessing algorithm animations as learning aids. In M. Brown, J. Domingue, B. Price, and J. Stasko (Eds.) "Software Visualization: Programming as a Multimedia Experience". The MIT Press, Cambridge, MA, pp. 417-438 (1998).

[8] R. C. Clark and R. E. Mayer. E-Learning and the Science of Instruction. Wiley: San Francisco (2003).